

DRAFT Brown Trout (*Salmo trutta*) Thermal Tolerance Analyses – Juvenile and Adult, Summer
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Introduction

Recommended summer chronic and acute thermal tolerance values for juvenile and adult brown trout and their justification are discussed below. The recommended tolerance values were developed in accordance with the “*DRAFT Methodology for Developing Thermal Tolerance Thresholds for Various Fish in Nevada – Juvenile and Adult, Summer*” (September 2015).

Chronic Thermal Tolerance Thresholds

Table 1 provides a summary of the range of chronic temperature tolerance values for brown trout for various lines of evidence. These values are based upon a review of sixteen papers and publications, the details of which are summarized in Attachment A.

There is obviously a wide range of temperatures from which to select an appropriate value and best professional judgment is called for. NDEP’s approach is to accept the EPA recommendations from Brungs and Jones (1977) unless the literature review provides a compelling reason to utilize other values. EPA’s chronic value of 17°C falls within the upper end of the range of potential criteria found in the literature, and is recommended as the chronic thermal tolerance level for adult/juvenile brown trout. As discussed in the methodology, chronic temperature criteria are generally not set to ensure the most optimum conditions. In fact, Brungs and Jones (1977) recommends that a chronic criterion for a given fish species be between the optimum temperature and the UUILT.

Table 1. Summary of Chronic Temperature Tolerances

Category	Temperature (°C)
Laboratory Optimal Growth Studies – Constant Temperature	
Optimum	12.8 – 19.0
Upper Optimum	15.0 – 19.6
Laboratory Temperature Preference Studies	
Average Preferences	11.7 – 18.5
Upper Preferences	13.7 – 22.8
Laboratory Upper Temperature Avoidance Studies	15.0 – 25.0
Field Growth Studies	13.2 – 16.5
Field Temperature Preference Studies	21.0 – 25.3
Thresholds from EPA and Colorado (MWAT)	17.0 – 19.6
Recommended Chronic Temperature Tolerance (MWAT)	17.0

Acute Thermal Tolerance Thresholds

Table 2 provides a summary of the range of acute temperature tolerance values for brown trout for various lines of evidence. These values are based upon a review of ten papers and publications, the details of which are summarized in Attachment B.

For ease of presentation, the UILT and CTM values have been summarized by acclimation temperature ranges. However as discussed in the methodology document, only the UILT and CTM values for acclimation temperature near the recommended chronic criterion (17°C) are to be included in the acute criterion development process. For brown trout, UILT and CTM values for acclimation temperatures of 15 - 20°C are utilized for criterion development.

Table 2. Summary of Acute Temperature Tolerances

Category	Temperature Tolerances (°C)	Potential Acute Criteria (°C)
Laboratory Lethal Studies – UILT/UUILT		
UILT		
Acclim. = 5 - 10°C	22.5 – 24.5	
Acclim. = 10 - 15°C	24.2 – 26.2	
Acclim. = 15 - 20°C	24.4 – 26.5	22.4 – 24.5 ¹
Acclim. = 20 - 23°C	24.8 – 27.8	
Laboratory Lethal Studies – CTM		
Acclim. = 10 - 15°C	24.8 – 30.0	
Acclim. = 15 - 20°C	24.8 – 30.0	19.0 – 24.2 ²
Field Studies	22.9 – 27.6	22.9 – 27.6
Thresholds from EPA and Colorado	24.0 – 24.6	
Recommended Acute Temperature Tolerance (MDMT)	24.0	

¹UILT and UUILT values reduced by 2°C to provide 100% survival (See *Methodology*)

²CTM values reduced by 3.8°C to estimate quasi-UILT values. Quasi-UILT value then reduced by 2°C to provide 100% survival (See *Methodology*)

A review of laboratory and field studies suggest that an appropriate acute criteria should fall between 19.0 and 24.5 °C, while field studies suggest a wider range of 22.9 to 27.6°C. This is obviously a wide range from which to select an appropriate value and best professional judgment is called for. NDEP's approach is to accept the EPA recommendations from Brungs and Jones (1977) unless the literature review provides a compelling reason to utilize another value. EPA's acute value of 24°C falls within the upper end of the range of potential criteria found in the literature, and is recommended as the acute thermal tolerance level for adult/juvenile brown trout.

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ATTACHMENT A

Detailed Summary of Chronic Thermal Tolerance Values for Brown Trout, Juvenile and Adult, Summer

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Table A-1. Chronic Temperature Tolerances – Laboratory Optimal Growth Studies, Constant Temperatures

Reference	Age or Size	Acclim. Temp. (°C)	Optimum Growth Temperature		Upper Optimum Growth Temperature	
			Temp. (°C)	Comment	Temp. (°C)	Comment
Brown (1946)	2-year	4.5 - 20	16 - 19			
Elliott (1975)	Initial wt. 10 – 350 g	na	12.8 – 13.6		15.0	Temperature at growth rate = 80% of optimum
Elliott et al. (1995)	Initial wt. 1 – 350 g	na	13.1 – 13.4		15.0	Temperature at growth rate = 80% of optimum
Elliot and Hurley (1999)	Initial wt. 1 – 350 g	na	13.9		<18.7	Zero growth at 18.7°C
Elliot and Hurley (2000)	Initial wt. 250-318 g	na	17.0	Optimum growth in energy terms		
Forseth and Jonsson (1994)	2 – 4 year	na	16.0		16.5 – 18.0	Temperature at growth rate = 80% of optimum
Ojanguren et al. (2001)	Juvenile	12 - 13	16.9		19.6	Temperature at growth rate = 90% of optimum

Table A-2. Chronic Temperature Tolerances – Laboratory Preference Studies

Reference	Age or Size	Acclim. Temp. (°C)	Average Preference Temperature		Upper Preference Temperature	
			Temp. (°C)	Comment	Temp. (°C)	Comment
Cherry et al. (1977)	<1 year	12 - 24	11.7 - 18.5		16.2 – 22.8	Upper 95% confidence limits on averages
Larsson (2005)	<1 year	8	16.0		17.5	Maximum preference for 75% of test fish
Reynolds and Casterlin (1979)	Adult	0 - 5	12.2		13.7	Average maximum for 6 test fish

Table A-3. Chronic Temperature Tolerances – Laboratory Upper Temperature Avoidance Studies

Reference	Age or Size	Acclim. Temp. (°C)	Temperature (°C)	Comment
Cherry et al. (1977)	<1 year	12 - 24	15 - 25	

Table A-4. Chronic Temperature Tolerances – Field Studies, Growth

Reference	Age or Size	Acclim. Temp. (°C)	Optimum Growth Temperature		Upper Optimum Growth Temperature	
			Temp. (°C)	Comment	Temp. (°C)	Comment
Lobon-Cervia and Rincon (2011)	<1 year	NA	13.2		16.5	Temperature at growth rate = 80% of optimum

Table A-5. Chronic Temperature Tolerances – Field Studies, Preference

Reference	Temperature (°C)	Comment
Eaton et al. (1995)	24.1	Based upon 95 th percentile of 5% highest weekly average temperatures
Wehrly et al (2007) ¹	25.3	1 day Maximum daily mean temperature (MEANT)
	23.3	7 day Maximum daily mean temperature (MEANT)
	22.5	14 day Maximum daily mean temperature (MEANT)
	22.1	21 day Maximum daily mean temperature (MEANT)
	21.0	63 day Maximum daily mean temperature (MEANT)

¹Results based upon field observations of both brook and brown trout.

Table A-6. Chronic Temperature Tolerances – EPA and Colorado

Reference	Temperature (°C)	Comments
EPA (1977)	17	Recommended level as MWAT
Colorado WQCD (2007)	19.6	Recommended level as MWAT

ATTACHMENT B

Detailed Summary of Acute Thermal Tolerance Values for Brown Trout, Juvenile and Adult, Summer

DRAFT

Table B-1. Acute Temperature Tolerances – Laboratory Lethal Temperatures, UILT/UIILT

Reference	Size or Age	Acclim. Temp. (°C)	Test Duration	UILT	
				Temp. (°C)	Comment
Frost and Brown (1967)	Unknown	5	1-d	22.5	
		10		24.5	
		15		26.2	
		20		26.5	
		23		27.8	
		5	7-d	22.5	
		10		24.2	
		15		24.4	
		20		24.8	
		23		25.3	

Table B-2. Acute Temperature Tolerances – Laboratory Lethal Temperatures, Critical Thermal Maximum

Reference	Size or Age	Acclim. Temp. (°C)	Rate	Temperature (°C)	Endpoint
Carline and Machung (2001)	Juvenile	10.9	0.3°C/min. (18°C/hour)	28.1 – 28.7	Loss of equilibrium
		12		27.4– 29.0	
Elliot and Elliot (1995) ¹	1-year	15	0.0104°C/hour	24.8 ± 2.5	Loss of equilibrium
			0.0208°C/hour	25.0 ± 2.8	
			0.05°C/hour	25.3 ± 2.2	
			0.1°C/hour	26.0 ± 1.9	
			0.5°C/hour	28.6 ± 2.0	
			1°C/hour	29.7 ± 1.1	
			2°C/hour	29.9 ± 0.8	
			6°C/hour	29.9 ± 1.9	
			18°C/hour	30.0 ± 2.0	
	2-year	20	0.0104°C/hour	24.9 ± 2.4	
			0.0208°C/hour	25.0 ± 2.1	
			0.05°C/hour	25.3 ± 2.3	
			0.1°C/hour	25.7 ± 2.1	
			0.5°C/hour	28.5 ± 1.7	
			1°C/hour	29.5 ± 0.9	
			2°C/hour	30.0 ± 1.3	
			6°C/hour	30.0 ± 1.9	
			18°C/hour	30.0 ± 2.5	
Galbreath et al. (2004)	Juvenile	15	2, 4, 8, 24°C/day (0.08, 0.17, 0.33, 1°C/hour)	29.0 – 29.3	Loss of equilibrium
Grande and Andersen (1991)	2-3 months	17	2°C/day (0.08°C/hour)	26.2	Death

Table B-2. Acute Temperature Tolerances – Laboratory Lethal Temperatures, Critical Thermal Maximum (cont'd)

Reference	Size or Age	Acclim. Temp. (°C)	Rate	Temperature (°C)	Endpoint
Lee and Rinne (1980)	Juvenile	10	0.02°C/min (1.2°C/hour)	29.0	Loss of equilibrium
		20		29.9	
		10	Daily fluctuation of 6°C; increased 1°C every 48 hours (0.02°C/hour)	27.0 ²	Loss of equilibrium

¹ Temperature values are means and 95% confidence limits

² Maximum daily temperature with temperatures varying from 21 to 27°C

Table B-3. Acute Temperature Tolerances – Field Studies

Reference	Temperature (°C)	Comments
Wehrly et al (2007) ¹	27.6	1 day MAXT
	25.4	7 day MAXT
	24.6	14 day MAXT
	24.2	21 day MAXT
	22.9	63 day MAXT

¹MAXT = Maximum daily maximum temperature. Results based upon field observations of both brook and brown trout

Table B-4. Acute Temperature Tolerances – EPA and Colorado

Reference	Temperature (°C)	Comments
EPA (1977)	24	No metric (DM, MWMT, etc.) recommended
Colorado WQCD (2007)	24.6	Recommended level as DM